DETAILED HEAT ENERGY ANALYSIS OF GRID CONSTRAINED ISLANDS: CASE STUDY ISLE of ISLAY.

Name:

TADIWANASHE T MUJATI

Student No:

202155206

MSc Sustainable Engineering: Renewable Energy Systems & The Environment

Contents

University of Strathclyde Engineering

ABSTRACT

A detailed heat demand analysis looking into the domestic industry on Islay to determine the best approach for reducing heating oil consumption, and heat delivery diversification into efficient delivery systems. This research looks to determine the potential for Islay and its housing as they target net zero by 2050. By analysing the current heating demand profiles regarding and identifying areas of improvement. The study pays focuses on building performance and investment into EPC improvements.

The study attempts to evaluate the heating load and performance of Islay domestic properties based on building ages. The properties are categorised using the housing age survey provided by the Islay Energy Trust (IET): *House A: pre-1919, House B: 1919-1964, House C: 1965-1983 & House D: 1983-present*

House A has the worst insulation and House D as having the best insulation. The conducted calculations for heat demand show House D performs better and consequently has cheaper energy costs due to the better insulating materials used. House D also has the lowest heating demand of all properties because of this. Technical comparison of building performance v Heat delivery system is conducted, a heat pump system is also analysed as the heat delivery system replacing fuel oil. The results show heat pump reduces the heating energy demand across all property categories as well as energy cost. These calculations provide a snapshot of the importance of building fabric materials, building energy performance and the heat delivery system determining the overall house heating demands and energy cost.

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To IET and George Dean for his time and support and for putting a smile on my face- I hope to remain as passionate in life as you.

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To all the wonderful people on the study gang for the warm welcome to Scotland and every memory since.

Introduction:

For many years remote Islands such as Islay have faced challenges in meeting energy needs. Islay, a small Island on the west coast of Scotland relies on imported fuel oil and other fossil fuels to meet energy demand. Despite being connected to the mainland UK national electrical grid system these imported oils make up over 70% of the overall energy mix. This means the cost of energy is higher for Islay residents than the average mainland costs of energy (Wood Group, 2021).

Like other island communities' poor grid connection to the wider GB transmission and distribution network and over-reliance on imported energy supplies, Islands such as Islay face significant hurdles and challenges in decarbonisation and net-zero strategies. Reliability is a constant barrier with the long rural overheard cables being at risk of damage from the high wind conditions, without a backup connection to the electricity transmission network the energy supply is not secure. These barriers have meant there is an electricity consumption constraint on Islay making the energy transition from fossil-based energy to renewable supply difficult.

With the looming threat of global warming and the need to decarbonise the energy supply, research into island energy systems is accelerating. Heating fuels dominate the total demand across the Island at 80% of the overall energy demand. (Wood Group, 2021)

In 2021, Argyll and Bute council and the Islay Energy Trust announce the Island's commitment toward net zero emissions by 2045. Islay has a significant renewable energy resource of wind, solar and tidal capable of meeting the island's demand, however, these commitments require significant work on the grid network and broader energy system to work.

Background:

Islay is the fifth largest island in Scotland, located off the west coast around 40km long and 25km wide. The island is famous for its smoked whisky and is home to 9 distilleries with at least 3 more planned in the next 5 years.

According to the Scottish Government census conducted in 2011, there are 1479 households and 3228 residents, giving a population density of approximately 0.6 people per hectare. The islands' location just off the west coast of Scotland makes it home to promising renewable resource sites such as the sound of Islay and West Islay. ("Where's Islay?" n.d.)

The sound of Islay has been recognised as a site of great potential for tidal energy with high frequent occurring tidal velocities. Located on the west coast, gale force winds are not uncommon, making the west coast a promising wind farm site. As of January 2022, Power Renewables has been awarded the lease to build a 2GW wind farm.

As stated before, most of the island's energy is imported from mainland Scotland with the majority being fuel oil used for heating in homes and industrial processes (agriculture/distilleries) and petrol and diesel. Fuel oil and Kerosene make up roughly 80% of the total demand, as shown in figure 1 below. (Wood Group, 2021).

Islay has a single 33kV connection to the mainland UK electricity transmission grid, this circuit also runs through Jura and Colonsay, from Lochgilphead to Carsaig Bay and delivers 11kV into the island network for residential and commercial use. The community also have a 6MW diesel backup generator in case of grid failures and blackouts. According to the Islay Energy Trust, Islay experiences a power outage said to last up to 6 months every decade according to the Islay Energy Trust (IET).

Poor grid connections are not the only issues surrounding Islay's energy system. Residents on the island experience higher energy prices than mainland Scotland. Figures published in the 2019 report Islay Strategic Housing Overview, estimated that 53% of residents on Islay were living in fuel poverty. (Community Housing Scotland, 2019). As of 2022, we can anticipate this number to have grown by at least 20% based on Ofgem predictions.

With a limited grid supply network and heavy reliance on imported fossil fuels, Islay has a big task in decarbonising its energy mix and achieving net-zero goals. The main challenge on the route to decarbonisation is tackling heating demand across the Island. Housing plays a major role in this with a significant number of homes being built in 1919, meaning homes are difficult to heat with solid walls, with further issues caused by the talent gap.

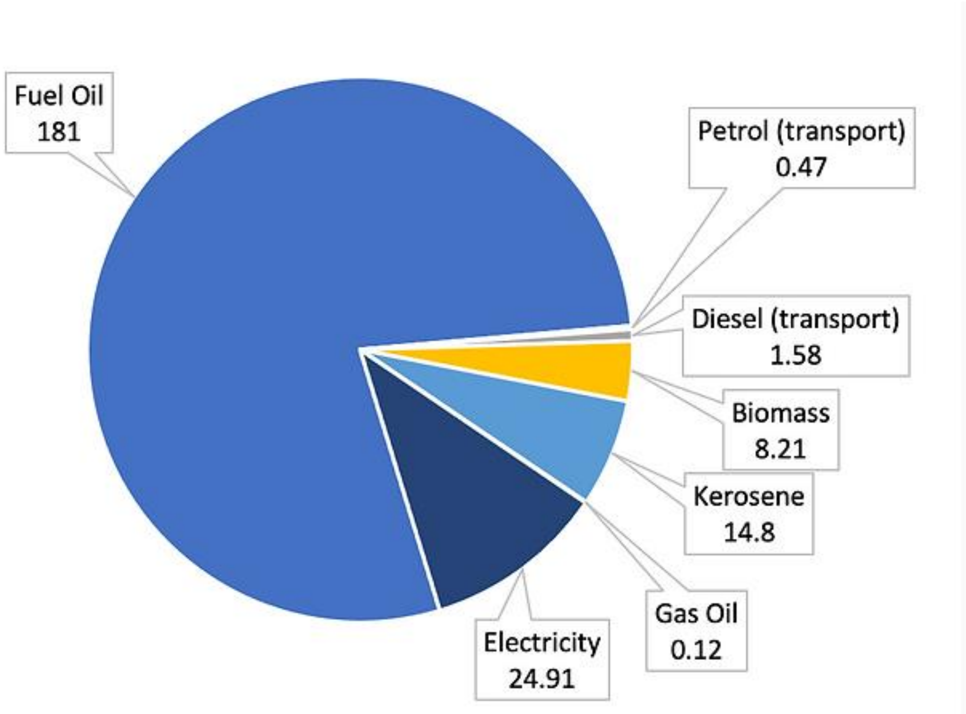

Figure 1: Energy Demand per Fuel Type on Islay (Wood Group, 2021)

This thesis will look at decarbonising heating demand on Islay. The Highlands and Islands Enterprise (HIE) conducted research into Scottish Island energy systems, and heating requirements were identified as a major barrier to net-zero targets.

In their Small Islands Energy System Overview, heating demands across the industrial and domestic sectors accounted for a large proportion of energy demand. Building stock and fuel poverty are also major issues across the Scottish Islands, with HIE finding most buildings rated EPC D and below. This research will focus on heat delivery, addressing net-zero goals and reducing fuel costs. Low carbon heating forms a wider part of the energy system addressing efficiency and system constraints, making a detailed analysis of heating demand a key process in Island net-zero goals. (Ricardo Energy & The Environment, 2020)

Literature Review:

Renewable energy resources have significant potential for economic, social, and environmental sustainability for an island and small communities. With decarbonisation goals, renewable energy not only provides clean energy but, in most cases, where communities are isolated from the grid network, they can improve access to energy. For Islands such as Islay, renewable energy has a significant contribution to make in creating a sustainable, affordable energy system.

Jaramillo-Nieves & Del Río (2010) state that access to energy plays a major role in sustainable development for nations and indeed for islands where geographical positioning makes them vulnerable to increased fossil fuel prices where electrical grid connections are limited. With the transition goals at the forefront of political debates, the renewable energy and sustainable development of islands in discussions is becoming an increasingly important topic. Islands are now included in cooperation agendas in international initiatives (e.g., UN Sustainable Goals).

European nations such as Norway have begun developing renewable energy projects on their islands using the natural resources available such as wind energy and solar for heating. Outside of these individual goals more partnerships, initiatives and networks are being created allowing for development, collaboration, and investigation into technologies as part of a broad effective policy framework for meeting the needs of islands such as Islay. (Jaramillo-Nieves & del Rio, 2010)

Islands around the world have different needs and landscapes but they tend to share similar features relevant for energy transitions, Islands are usually isolated from the main UK grid and typically have poor infrastructure. They also lack indigenous fossil fuel reserves making them dependent on imported fuel energy meaning residents tend to pay more for their energy as a result. In addition, most islands tend to be rich in renewable energy sources such as wind, solar and ocean.

Torabi, Gomes, and Morgado-Dias (2021) identify the lack of a flexible electrical network as a barrier to large-scale investment into renewable energy projects on islands. They state: that *"the lack of interconnections and the economy of scale of some RES projects may account for why RES projects on large scales are not economically attractive on islands*" (Torabi, Gomes, and Morgado-Dias, 2021). Indeed, the biggest challenge faced by many island and rural communities remains the economic feasibility of transition. Transition means changes to infrastructure and investment into new renewable energy technologies.

IRENA (2016), states that small islands can meet most, if not all their energy needs through a combination of renewable energy technologies. IRENA also states the major barrier to transitioning islands is the cost of technologies. In 2014, the Small Island Developing States (SIDS) Lighthouse Initiative was launched at the Climate Summit. The SIDS Lighthouse Initiative (LHI) provided a global framework for energy transition on islands and sets out three aims:

- Ensure participating nations develop RE roadmaps
- Mobilise $500 million (USD) for investment into island renewable energy investment
- Deploy a 120MW RE generation capacity (100MW, Solar & 20MW Wind.)

Since its launch in 2014, the 36 partners have achieved a combined 3.5 GW RE installed capacity by the end of 2019. According to the IRENA SIDS Lighthouse Initiative: Progress and way forward (2021), all SIDS partners have now adopted renewable energy as key components in their energy policy frameworks. In the period between 2014-2019, wind and solar energy accounted for the greatest increase in installed capacity and Hydropower capacity dropped, as shown in Figure 2. Geothermal energy has seen no changes over the same period.

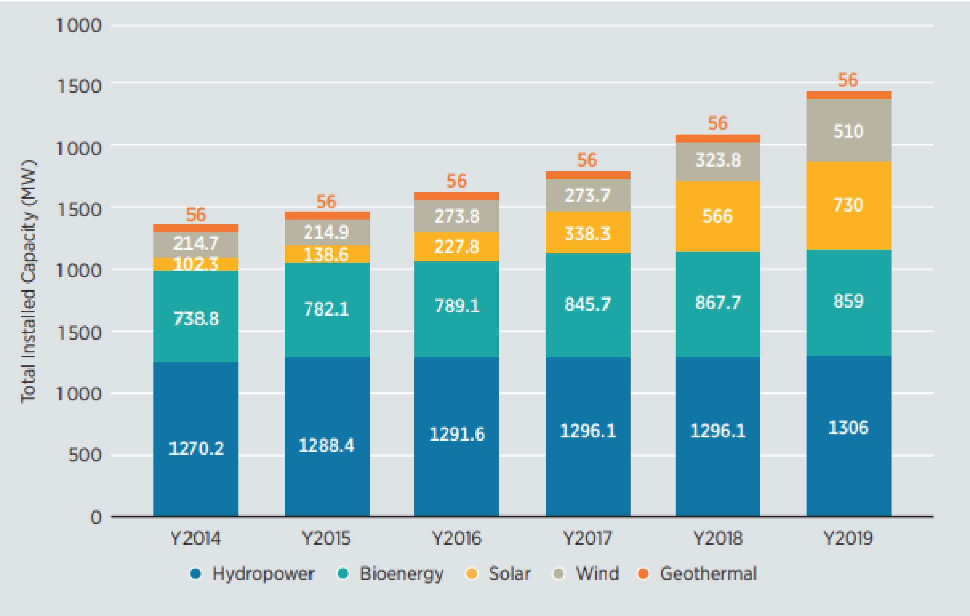

Figure 2: IRENA Statistics for SIDS

Beyond 2020, International Renewable Energy Agency (IRENA) has set new targets for the nations and partners, with renewable energy transformation investment continuing to be a key target. They have revised their aims, looking ahead to 2020, SIDS nations are aiming to achieve 5GW installed renewable energy capacity combined across its 41 partners (5 more have signed on since 2019) by 2023 (IRENA, 2021)

Energy transition has made island energy security vulnerable, Islands such as Islay that are largely reliant on the import of fuel oils will suffer from increasing energy costs. But the solution is not so simple and energy transition is subject to widespread challenges such as geographical positioning, power grid connection, infrastructure, and population distribution.

Energy transition for each island is largely impacted by the geographical location leading to different approaches and goals being researched by energy engineers. In India (Bhakta & Mukherjee, 2017) solar PV technology and battery storage systems have been researched for electricity generation. This techno-economic study looked at the reliability and flexibility of a storage operating PV electrical system replacing fossil-fuel generation long-term. This finds that for isolated islands in India (Andaman and Nicobar) this energy system can meet the demand and is economically feasible. It is key to note this is possible as there is enough solar irradiation and a small industry on the islands. Larger and more energy-intensive Islands would require alternative strategies for transition. (Bhakta & Mukherjee, 2017)

Another economic feasibility study looked at Popova Island focusing on integrating renewable energy using the Monte-Carlo method (quantitative risk analysis). This study looked at hybrid optimisation of the energy system by putting differing amounts of RES in the supply to determine optimal financial penetration. The outcome aimed to communicate the financial potential for increased renewable energy within Popova's energy mix and reduce energy costs for its residents. It was concluded renewable energy shares above 46% within the energy mix led to increased system costs. (Uwineza, Kim, & Kim, 2021)

Transitioning Islands Energy Systems by Marczinkowski et al (2019), the energy systems are analysed via a smart grid solution for three European Islands Orkney, Samso and Madeira. This paper highlights the issue with transitioning islands - t*here is no one size fits all approach*. The islands have differing geographical layouts and population distribution patterns, this study considers local demands, existing RE utilisation and RE availability. In line with the "EU Clean Islands" 2030 scenarios –using the software EnergyPLAN, to conduct short-term analysis for the transition of three energy systems, changes such as weather conditions are neglected and so only account for the current conditions over a period. The study concluded on the route to 100% renewable energy for Islands, efficient heating options must be addressed and fossil fuel demand by 2030 can be reduced but remains in the energy system. Local conditions and strategies influence the pace of transition making the transition for each Island unique.

All the existing literature studied highlights the importance of Island energy transition in the context of climate change and fuel poverty. The literature reiterates the important role of reliable electrical grid networks and electrification methods for decarbonisation pathways. No studies found focussed on peak demand and load profile shapes in the context of heating, which many identify as the most carbon-heavy sector for island regions. This thesis aims to cover this gap in the literature by examining how load profiles can change based on chosen delivery system, as different methods of electrification and decarbonisation can significantly impact consumption habits. Peak demand data determine the Island's capacity needs and highlight investment opportunities and areas for improvement. Allowing for strategic and intelligent planning of the energy grid.

Methodology:

This section highlights the method and technical details conducted on Islay's domestic sector, Heat demand profile analysis and simple financial analysis of potential heating delivery methods.

Buildings account for 40% of the total Global emissions, they're major energy consumers. On Islay there is a power imbalance across buildings regarding demand distribution, Whisky Distilleries combined to hold the biggest heating demand on the Island, however, each distillery size is very different meaning heating demand is not evenly distributed. A detailed analysis of the heating demand profiles allows for a sector-specific approach to be applied for the recommendation of a suitable decarbonisation strategy.

This thesis focuses on domestic heat demand. Analysis of peak demand and supply through renewable resources is key, increasing RE generating ability and implementation into a grid system is a potential solution, however, these are expensive undertakings for a small island such as Islay. Understanding the scale of decarbonisation challenges, generation requirements and methods for delivery is key. With the knowledge and understanding of heat demand over time, information on peak demand and the rate of change in demand can be gathered.

To analyse the current heating demand of Islay, heat demand profiles must be analysed either on an hourly, weekly, or monthly basis. To achieve this hourly demand and supply data relating to the Islands heating must be obtained. Hourly demand profiles supply an in-depth analysis of an annual demand profile that will look at 8760 hours of data. The analysis will be applied to assess the heat energy profiles within the domestic

For annual heating requirements for domestic properties, Islay Heating Degree Days (HDD) is used. HDD is a measurement used to quantify the demand for energy to heat a building. Heat degree days provide a simple quantification as we can in principle assume the energy needed to warm a building is directly related to the outdoor temperature and thus proportional to the heat degree days of that period.

Challenges Of Analysis:

The challenge with Islay is there is no hourly demand data available for Islay. The current energy system is not automated and so there are no simple ways to track the energy use of properties. A simplified model was applied which used the data provided by the Islay Energy Trust (IET).

The data provided has been gathered from a variety of sources including council tax records. From these records, IET, estimates there to be approximately 2000 domestic properties, of this approximately 350 are registered second properties/holiday lets. Council tax records show primary residences, many of which are classified as “family homes” however they may not accurately represent their occupancy status. Some of these family homes where parents have passed but the families retain ownership and use these properties as second homes may not be accurately recorded. From the available sources, the housing of an estimated 1600 properties can be assumed as “always occupied” with the rest being “holiday homes”.

Another key requirement for generating the demand profiles was the age of the properties, as this can significantly affect the building efficiency and therefore heating demands across each building type by age would differ. The IET and Argyll & Bute council can establish the age profile of 1600 properties as follows:

pre-1919: 44%

1919-1949: 7%

1950-1964: 9%

1965-1983: 22%

1983-present: 18%

Assumptions:

The study is conducted based on available house data such as building materials, building age, average floor area, number of residents, and Energy Performance Certificate bandgap. As it is not possible to get detailed floor plans of the housing on Islay, a standard 3-bedroom floor plan is assumed.

The data for building ages decides the parameters that are considered to categorise the different housing scenarios on Islay highlighting different insulation (this has been informed by available building regulation data) and determining the impact insulation and building age have on the energy demand of domestic properties on Islay. The housing scenarios are broken down by age profile as defined by IET as defined:

House A: pre-1919
House B: 1919-1964
House C: 1965-1983
House D: 1983-present

Table 1:The following dimensions for a standard 3-bedroom UK home are applied (Davies, 2016)

Roof Area	$50m^2$
Floor Area:	50 m^2
Ceiling Area:	50 m^2
Wall Area	125 m^2
Windows/doors area:	25 m^2
House volume:	$250m^3$
Average House size:	100sq m.

Average areas and fabric data were obtained which align with Part L of the Building Regulations UK.

For annual heating requirements for domestic properties, Islay Heating Degree Days are used. Heating Degree Days (HDD) is a measurement used to quantify the demand for energy to heat a building. Heat degree days provide a simple quantification as we can in principle assume the energy required to warm a building is directly related to the outdoor temperature and thus proportional to the heat degree days of that period.

There was no available data for pre-1919-1960 Data. Therefore, Energy Consumption for buildings from this period has been given an overestimation factor of 1.3 has been applied to the earliest available fabric materials data.

Data Analysis:

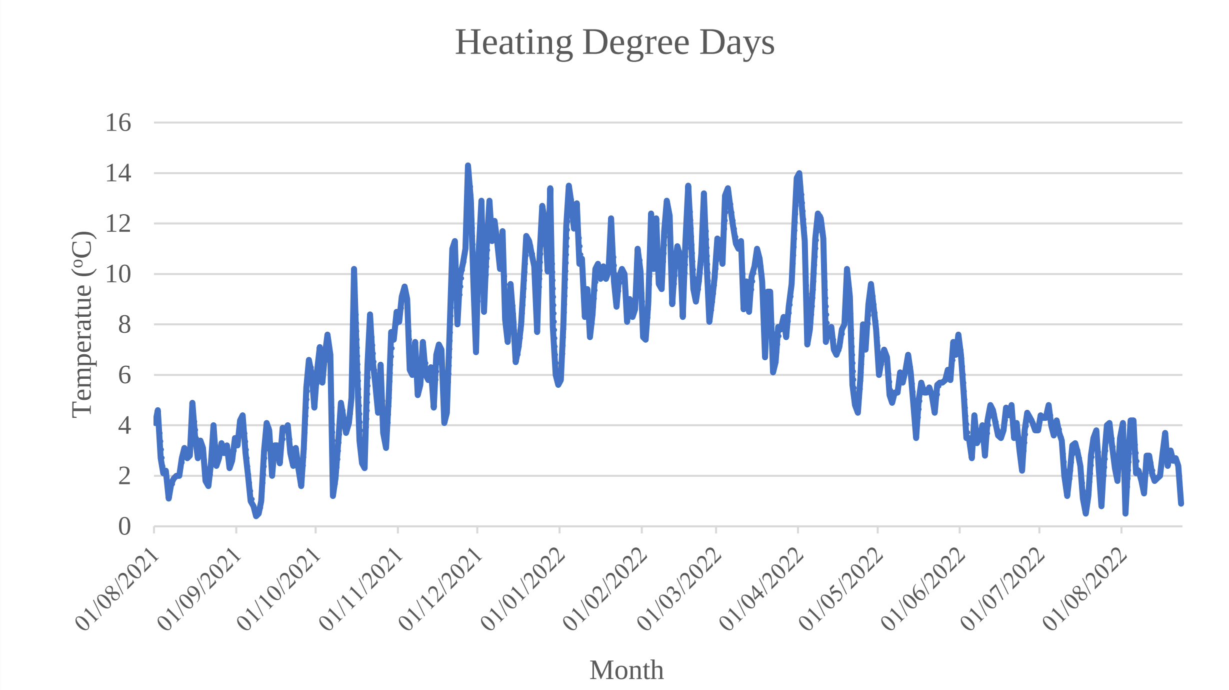

Figure 3: Islay Heating Degree Days (Degreedays.net)

Heating demand calculations, 2020 heating degree days from the closest meteorological station, Islay EGPI Station (6.26W, 55.68N) taken from 'www.degreedays.net'. The base temperature used is 17°C, this means the properties do not require any supplementary heating at this temperature or above. Periods of High HDD represent high demand periods.

Table 2:Typical U-Values based on building regulations & regulations & Minimum standards (U-Value W/m2.K) (Davies, 2016)

Component (W/m2.K)	1965	1980	1990	2000	2010	2016
Roofing	1.4	0.6	0.45	0.35	0.25	0.25
Wall	1.6	1	0.6	0.45	0.30	0.18
Ceiling	1.5	0.68	0.4	0.35	0.20	0.13
Floor	1.2	1.2	1.2	0.51	0.22	0.13
Window/Door	4.8	4.8	4.8	3.1	2.0	1.4

Table 3: Building Heat Loss & Consumption based on building regulations per decade

Year	1965-75	1980	1990	2000	2010	2016
Heat Loss Coefficient ($W\,K^{-1}$)	690.00	534.00	462.50	359.25	286.00	248.00
Annual Demand (kWh)	41,459.62	32,086.14	27,789.96	21,586.04	17,184.71	14,901.43
Daily Demand (kWh)	113.59	87.91	76.14	59.14	47.08	40.83

Table 3 shows the comparative difference of each house based on the change in the building regulations made. It Highlights how changes and improvements in building materials impact the building performance and therefore the heating demands. The calculations conducted in table 3 are simplified and based only on fabric heat losses, no other factors such as equipment, occupancy or heat delivery systems are considered. The equations listed below are used to conduct all calculations in Table 3 and will be applied for analysis of the heating delivery systems (Heat pump & Fuel Oil Boiler)

Heat demand (kWh) = Q_d **(kW/k) x** ΔT **(°C) x 24(hr/day)**

Equation 1: Heat Demand

Q_d **= Qv / ΔT x Σux**

Equation 2: Overall Heat Loss Coefficient

Where:

Q_d= Heat Loss Coefficient

Σu_x= Sum of fabric U-values

ΔT= Inside – Outside Temperature Difference. In this case: HDD = ΔT

Q_v= Ventilation Contributions towards the overall Heat Loss Coefficient

Q_v is given by the equation: **Qv / ΔT (WK^{-1}) = (0.33 × n × V)**

Equation 3: Ventilation Heat Losses

Where:

n= number of air changes per hour. The analysis assumes n of 1.5 for all properties

V= Volume of the house in m^3

Peak heating load(kWp)= (hourly average load + 33%)/Total Hours

Equation 4: Peak Heating Load

Assuming heating is at peak between 7 am-9 am and 5 pm-9 pm.

Data Sample is 388 days = 9,312hrs

(The Open University, n.d.)

Comparison: Fuel Oil Vs Heat Pumps

The aim to reduce and cut the GHGs associated with heating delivery requires the decarbonisation of heating delivery systems. The building fabric design, EPC rating and method of heating, and control system are of great importance to achieve optimal thermal comfort for occupants and increase the overall energy efficiency of the building while accomplishing Net-Zero goals. One of the ways this can be done is through the reduction of energy demand.

Table 3, highlights that by using more efficient materials it is possible to reduce heating energy demand. Shown by the drop in energy demand based on the Build age. The key driver in this reduction is the fabric U-values or fabric quality driven by evolving building regulations. In turn, this reduction of energy demand will reduce pressure on household energy bills, which helps tackle fuel poverty.

This section looks to further highlight this by looking at the transformation of the heat delivery system and how that changes the energy demand and the cost of energy.

Assuming a heat pump can reduce your electricity use for heating by approximately 50% compared to other heating systems such as furnaces and oil boilers. It can further reduce heating by 10% when switching from fuel oil burners. Therefore, we can estimate a 60% total reduction in energy consumption by switching to Heat pumps.

Fuel Oil:

$\mathbf{Q_d}$ = Qv / ΔT x Σux

Qv / ΔT ($\mathbf{WK^{-1}}$) = (0.33 × n × V)/0.9= *183.3*

*Assumed **10%** heat losses from fuel oil combustion.*

Cost per kWh = *£0.104 ("Confusedaboutenergy.com")*

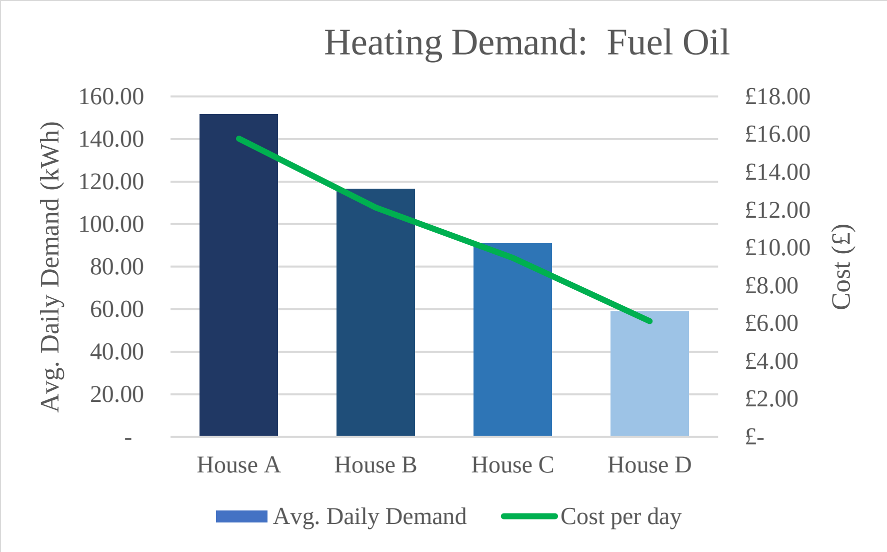

Figure 4: Annual Heating Demand Utilising Fuel Oil

Table 4: Energy Performance Estimations of different Building Types (Fuel Oil System)

Year	**House A**	**House B**	**House C**	**House D**
Heat Loss Coefficient (W K–1)	934.85	719.12	563.12	368.06
Annual Demand (kWh)	56,171.95	43,209.19	33,835.71	22,115.11
Avg. Daily Demand	153.90	118.38	92.70	60.59
Cost per day	£ 16.93	£ 13.02	£ 10.20	£ 6.66

Heat Pump:

The efficiency of the HP is given by the coefficient of performance (COP) which is the ratio between thermal output and electricity input. Typical household heat pump systems have a COP of 2.5

Heat Loss Coefficient = Qv / ΔT x Σux

Qv / ΔT (WK^{-1}) = (0.33 × n × V)/0.1= *165*

Cost per kWh= *£0.19* (Wood Group, 2021)

Demand Reduction assumed to be **60%**

Heat pumps are taken as 100% energy efficient therefore no other heat losses from the system are accounted for.

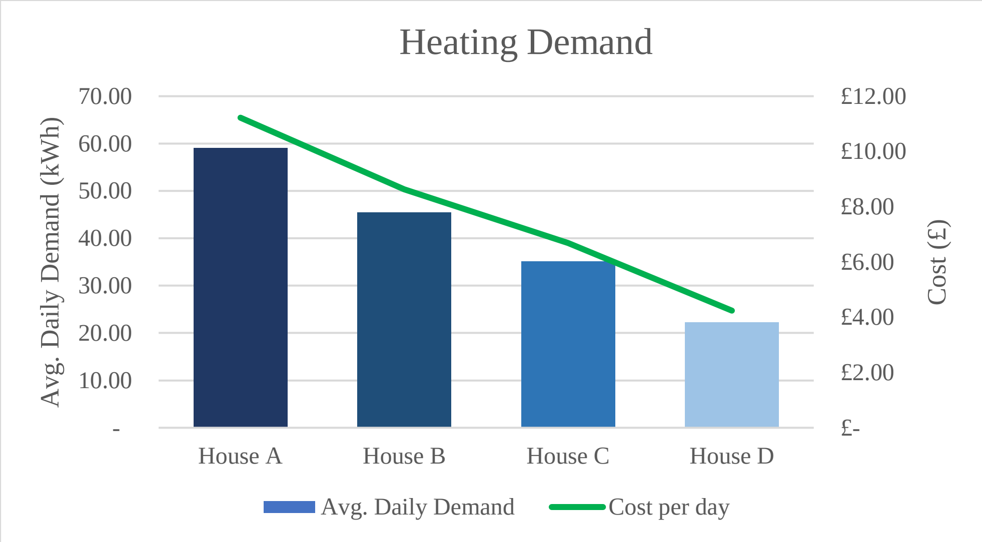

Figure 5: Annual Heating Demand Utilising Heat Pump

Table 5: Energy Performance Estimations of different Building Types (HP System)

	House A	House B	House C	House D
Heat Loss Coefficient (W K–1)	897.00	690.00	534.00	338.94
Annual Demand (kWh)	21,559.00	16,583.85	12,834.46	8,146.21
Avg. Daily Demand (kWh)	59.07	45.44	35.16	22.32
Cost per day (£)	11.22	8.63	6.68	4.24

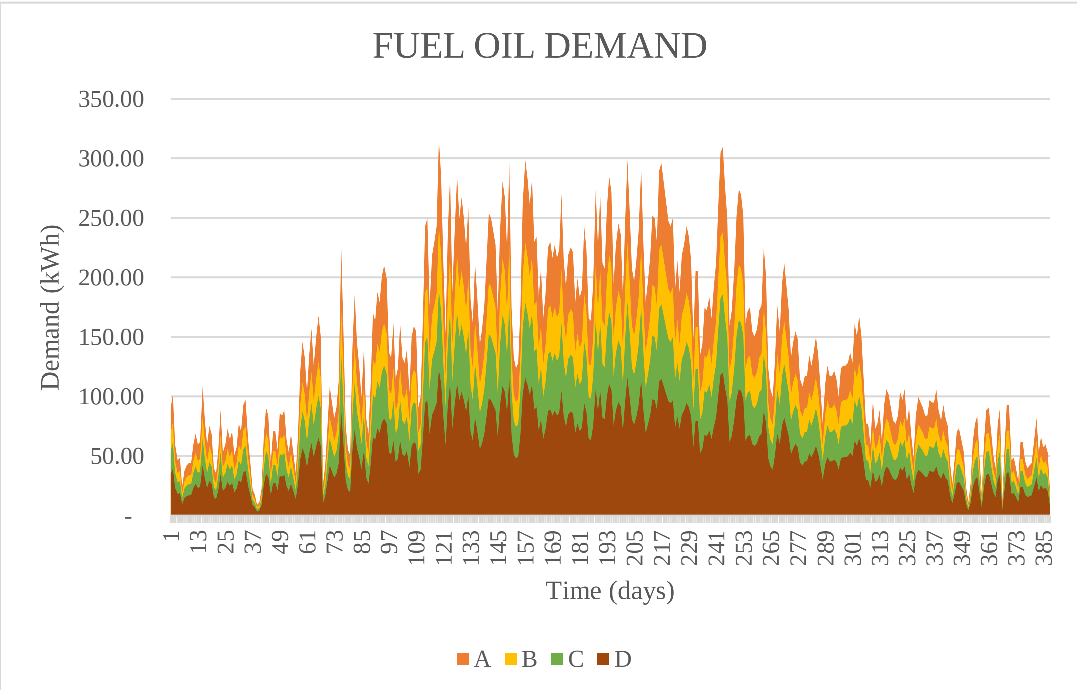

Figure 6: Annual Heat Demand with Fuel Oil

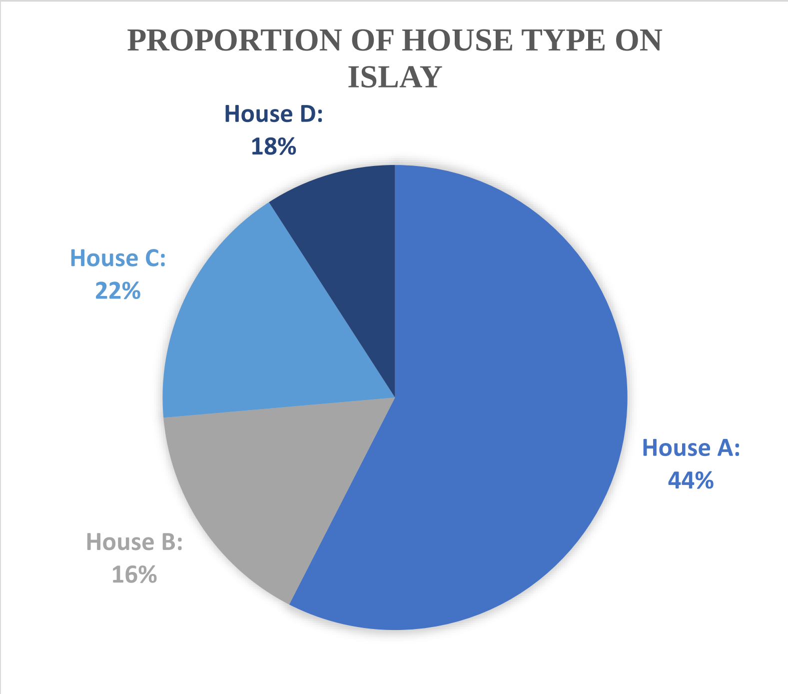

Figure 7: Annual Fuel Oil Breakdown by Build Age

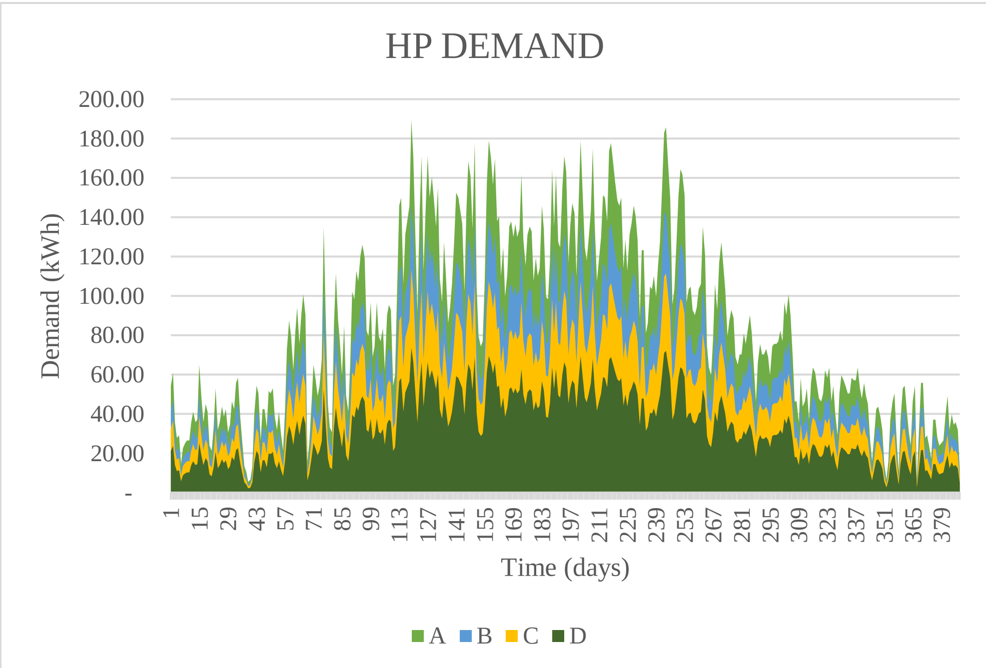

Figure 8: Annual Heat Demand with Heat Pump

Tables 4 & 5 show the estimated annual energy demand/consumption per type of household with the given heat delivery system.

Graphs 6 & 8, highlight how changing the heating system has a significant impact on the overall demand/consumption trend for each house type. This is further by the decrease in daily demand and cost per day to heat the home. Energy costs decrease by 33% across all the properties.

The average house uses 12,000kWh annually to heat their homes, (Viessmann, n.d.), from Tables 3 & 5 over 80% of homes in Islay are over this for their heating needs. With the introduction of the HP system in table 5, we can see these decreases to 60%, a significant decline. Assuming the entire domestic sector improved their homes to meet House C (1963-85) building standards it may be possible for 80% of Island properties to see drastic energy savings of up to 60% approximately £3,741 annually for those living in House A (44% of Islay residents).

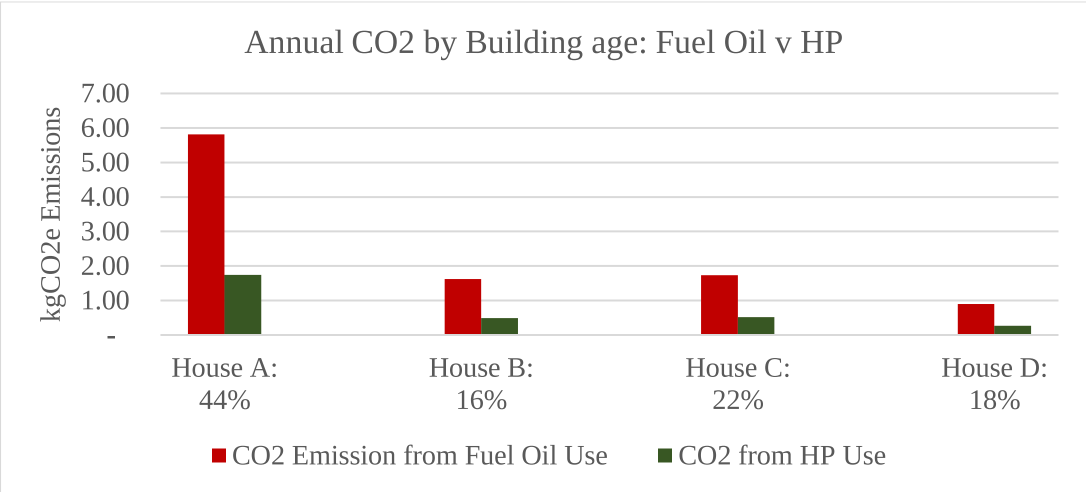

Figure 9: Annual kgCO2e Emission per Building Age

Replacing the heating delivery system from fuel oil to HP will significantly reduce the net GHG emissions. Fuel oil emits over 70% more grams of CO2 per kWh than GSHP systems. Fuel oil can release up to 0.55kgCO2e per kWh whereas GSHP will release up to 0.125kgCO2e per kWh. (Cole, 2020)

This is because fuel oil involves the direct combustion of fuel releasing CO2 and other GHG, not the air. Heat pumps have a smarter design and are designed to minimise emissions with a COP of around 350%, they work with refrigerant gas inside the network of pipes. The gas flows through a cycle of evaporation and condensation as it absorbs heat, the gas then changes into a vapour that is compressed by an electric pump. This compression step helps to concentrate the energy stored in the refrigerant. As the refrigerant cools heat is transferred into the water tank.

This means the most carbon-intensive step is compression where an electric pump is used, there is no direct combustion thus reducing emissions.

Financial Analysis of Options: Retrofit v HP

Cost of Increasing Build Efficiency:

Energy Performance Certificates (EPC): An Energy Performance Certificate reviews a property's energy efficiency, it is often used as a quick graphic to showcase how much energy bills a property will be. The key information highlighted in EPC reports includes

- The amount of energy a property uses
- The amount of CO_2 emissions
- Ways to further improve the property's carbon footprint and reduce energy costs.

In Islay, approximately 50% of residential properties do not have an EPC rating, with the average rating sitting below EPC D (the Scottish Average). With most homes being built before 1919 it is we can assume they have an EPC score of E or less.

While there are currently no legal requirements to achieve a minimum EPC rating policies are coming into place in 2025 outlining energy efficiency rules. To achieve 2050 net-zero ambitions, Islay residents will need to look at upgrading their homes. The new Minimum Energy Performance of Buildings Bill set for 2025 is part of the Clean Growth Strategy and will place the legal burden on homeowners to increase EPC ratings to a minimum D score (GOV.UK, 2017).

Current estimates by the Scottish Government estimate that the average cost of upgrading a single dwelling for each EPC band, they're outlined in the tables below:

Table 6: EPC Upgrades F-E (GOV.SCOT, 2020)

Cost Of EPC Upgrades: EPC F/G to EPC E:	
Upgrade Cost (Incl hidden cost estimation) (£)	1,250
Post Upgrade Cost (New EPC Certification) (£)	70
Annual Energy Bill Reduction (£)	330
Simple Payback Period (yrs.)	4
Annual Carbon Savings (tonnes/kgCO2e)	1.6

Table 7: EPC Upgrades F-D (GOV.SCOT, 2020)

Cost of EPC Upgrades: EPC F/G to EPC D:	
Upgrade Cost (Incl hidden cost estimation) (£)	2,700
Post Upgrade Cost (New EPC Certification) (£)	70
Annual Energy Bill Reduction (£)	320
Simple Payback Period (yrs.)	9
Annual Carbon Savings (tonne/kgCO2e)	1.7

Table 8: EPC UPGRADES E-D (GOV.SCOT, 2020)

Cost of EPC Upgrades: EPC E to EPC D:	
Upgrade Cost (Incl hidden cost estimation) (£)	2,010
Post Upgrade Cost (New EPC Certification) (£)	70
Annual Energy Bill Reduction (£)	190
Simple Payback Period (yrs.)	12
Annual Carbon Savings (tonnes/ kgCO2e)	1.1

Improving building efficiency can reduce heating-related emissions by 25-35%. They can also reduce energy bills. While the above calculations show this annual reduction, the first investment means homeowners do not make an immediate profit. The shortest payback period is 4 years when upgrading from rating G to E.

It is key to note these savings are not cumulative of the savings made with upgrades to EPC E initially. I.E., the total annual bill reduction including savings already made with upgrading to EPC E prior would be £520 and a total Carbon savings of 2.7t kgCO2e. However, with this route the homeowner spends more money, it is cheaper to upgrade directly from rating F to D at £2,700. Investment into the staggered approach F to E and then E to D means homeowners pay out £560 more and have a longer waiting period before their investment appreciates and starts making a profit.

The estimated cost of retrofit does not consider isolated areas such as Islay where there is a skills shortage, therefore expect the cost of retrofitting to be larger than these estimates.

Limitations to EPC Improvements:

In the UK the built environment, including housing responsible for approximately 25% of total GHG emissions. To tackle these carbon targets and green policy is planned by the Government to increase energy efficiency and reduce energy demand thereby reducing emissions. The Government states they will prioritise the reuse and retrofit of buildings. However as highlighted by the economics retrofit can be a costly endeavour, with the Government aiming for the introduction of Green Bills which sets a baseline EPC rate for all homes.

According to Milner, 2021, there are currently around 29 million homes in the UK, of which 19 million have an EPC lower than C. She estimates the cost of upgrading from EPC D to EPC C is estimated to be a minimum of £6,000. This could see the UK national retrofitting bill go up to £38 billion. (Milner, 2021)

The Government calculations only provide a baseline, and it is predicted the costs of improvements increase with building age. There are currently around 70% of homes in Islay, have an EPC lower than D with over half of the properties dating back to 1965 and before, retrofitting is a costly undertaking for the Island and its residents who already live in fuel poverty. Lack of education and lack of skilled workers on the Island further increase the costs associated with these home improvement projects, as they would need to find skilled professionals from Mainland Scotland which often comes with higher rates due to the length of the projects and travel involved

A number of the properties lie within conservation zones, meaning homeowners require permission before undertaking any retrofitting projects. on EPC ratings mean that most homeowners and Landlords do not understand EPC ratings or the government funding & resources available to support them. (GOV.SCOT, 2020)

Cost of Heat Pump Installation for household types:

Peak Heating Load (kWp) using Equation 4**:**

House A:	House B:	House C:	House D:
7.92	6.10	4.75	3.07

To estimate the cost of heat pump installation the following assumptions were applied for each property:

Property Type: Semi-Detached House

Number of bedrooms: 3 Bedrooms

Approximate Floor Area: 100m^2

All calculations are for the replacement of the heating delivery system, calculations do not consider refurbishment and EPC upgrading.

A simple Excel heat pump costing tool has been used to approximate the installation costs and fuel price savings listed in Table 9. The calculations below are based on an RHI tariff of 0.213/kWh for a ground source heat pump. Kensa Ltd state the following: housing data is based on estimated EPC figure by build ages and is assumed heating system Star Rating. RHI payment estimates reflect the 30,000kWh RHI cap. Energy costs are based on figures provided by Nottingham Energy Partnership (NEP). And electricity costs are based on an average of the Big Six electricity companies. (Kensa Heat Pumps Ltd, 2016)

An 8% fuel price inflation rate has been used when estimating running cost savings over the estimated payback period.

At the time of this study, the Renewable Heat Incentive (RHI) has ended as of March 2022, however, with the Energy Efficiency Buildings Bill underway it is expected to be reinstated soon.

Table 9: HP Cost Estimation for Household Types:

	House A	**House B**	**House C**	**House D**
HP Size (kW)	9	9	6	6
Installation Cost (£)	17,300	17,300	11,700	11,700
Payback Period (years)	6	6	6	7
Annual Fuel Cost saving (£)	280	251	82	69
RoR (%)	8.2	5.1	6.2	1.7
Estimated (KWh/yr.)	18,660	16,570	13,450	11,369
Running Cost (£)	863	768	745	630
Annual RHI (£)	2,471	2,507	1,872	1,582

Limitations of Heat Pumps Deployment:

The scalability of the heat pump on the Island is significantly affected by the poor energy supply network. To allow the estimated 1650 homes to be able to comfortably meet their heating demands without overloading the overhead cables at peak times further upgrades and investments are needed to reinforce an already constrained grid system (Wood Group, 2021).

With the introduction of heat pumps, it means the electricity demand will surge making a secure grid connection vital for the mass undertaking. This means full immediate replacement of fossil fuels with heat pumps is not a feasible undertaking. With oil and gas boilers being phased out in the UK by 2025, it is recommended that Islay homeowners and landlords look to retrofitting homes.

With 60% of the building fabrics dating back to 1965 or further, this means homes are poorly insulated, achieve thermal comfort is difficult to achieve. Transforming the heating delivery system to Heat pumps increases the running costs and electricity demand further adding strain on the grid.

As shown in this study energy materials in buildings can significantly impact the heating demand. Tables 3 & 4 show, that without transformation of heat delivery, House D, built with better insulating fabric experienced fewer heat losses and had a lower heating demand. This is further highlighted in Figure 4, where it is represented in the graph and the average daily demand is 60% less than that of House A which has the worst-rated building fabric. Targeting EPC performance of the building and reducing energy demand across the domestic sector will see the lowest impact on the grid with the quickest and cheapest results.

The calculations and results are provided as guidance only, as they do not account for all heat loss factors, and internal heat gain and rely largely on weather patterns to determine heating loads. The building fabric data and associated U-Values have been referenced from external academic and industry sources due to the limited data available on Islay. This study does not accurately represent heating demand and there is no way to differentiate space heating and water heating demands, demand is referred to as uniform. The assumptions made in the calculation and this study, therefore, offer an estimation, further detailed analysis of Islay's domestic sector is required to accurately map heating requirements.

Conclusion

With energy prices reaching historic highs, fuel poverty will continue to be one of the biggest energy challenges on Islay. Finding solutions to tackle and decrease the over-reliance on fuel oil and cut energy costs is becoming increasingly important every day. Geographical constraints remain the biggest barrier to the immediate implementation of HP systems and this introduction will need to be gradual due to the skill gap and cost of installation. As shown in this analysis improvements to building materials and retrofitting are cheaper and can significantly reduce energy demands and cost of energy for residents ensuring cheaper energy, reduced reliance on fuel oils, more energy efficient homes and reduced GHG emissions. Aligning with the UK government's focus of reuse and retrofitting older buildings is key to achieving Net-zero transition goals considering over 80% of homes on the Island are 35 years older. Improving the building efficiency makes HP systems an attractive heat delivery option.

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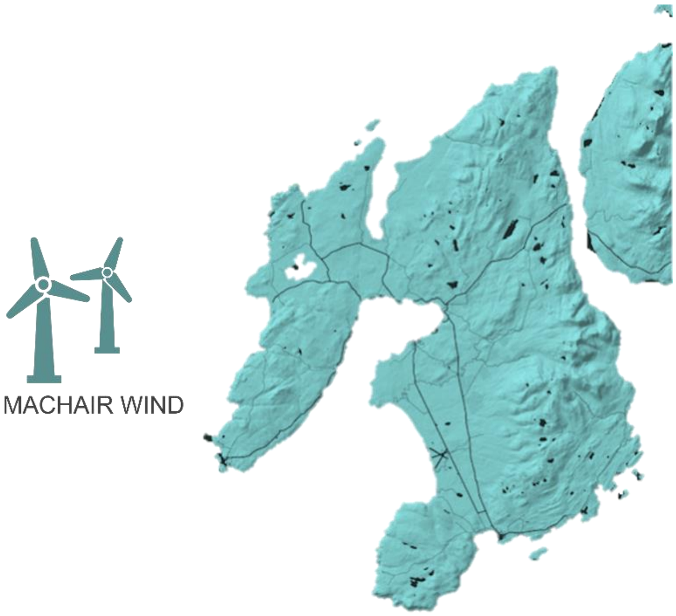
Appendix I:

RENEWABLE ENERGY & ITS ROLE:

MachAir wind farm is a Scottish Power wind site. A planned 2GW-sized wind farm is estimated to power over 2 million homes in Scotland. Scottish Power has signed a memorandum of understanding with Argyll & Bute Council and IET to give back between 4-8% of the total energy produced back to Islay and its residents.



Currently, the cost of energy is higher in Islay per person than it is across Scotland and the broader UK. With the introduction of Heat Pumps across the domestic sector, the cost of energy reduces. Introducing wind supply to help meet the heating demand will further reduce the LCOE as the energy tariffs for renewable electricity are lower than for oil and gas-generated energy. Calculations for potential generation of the MachAir wind site have been estimated in an earlier Strathclyde project looking at decarbonising Islay's whisky industry "Future Energy Systems for Islay" by the author of this study. The results clearly showed there is substantial renewable energy available to power heating on the island. (Del Valle et al., 2022)

The higher cost of energy can also be attributed to the cost of transporting fuel oil to the island, with generation from local Wind, transportation costs are cut out and so the cost of energy is reduced.

To determine the suitability of wind energy as an energy supply, it was graphed at the 4% feedback scenario as this can be considered the worst-case scenario for Islay. All calculations are done over 2 years and then averaged to provide annual estimations. The wind energy is estimated using the Siemens Gamesa SG 10-194 turbines Figure X shows the potential energy of the wind farm at 4% capacity and graphs alongside the heating demand of housing.

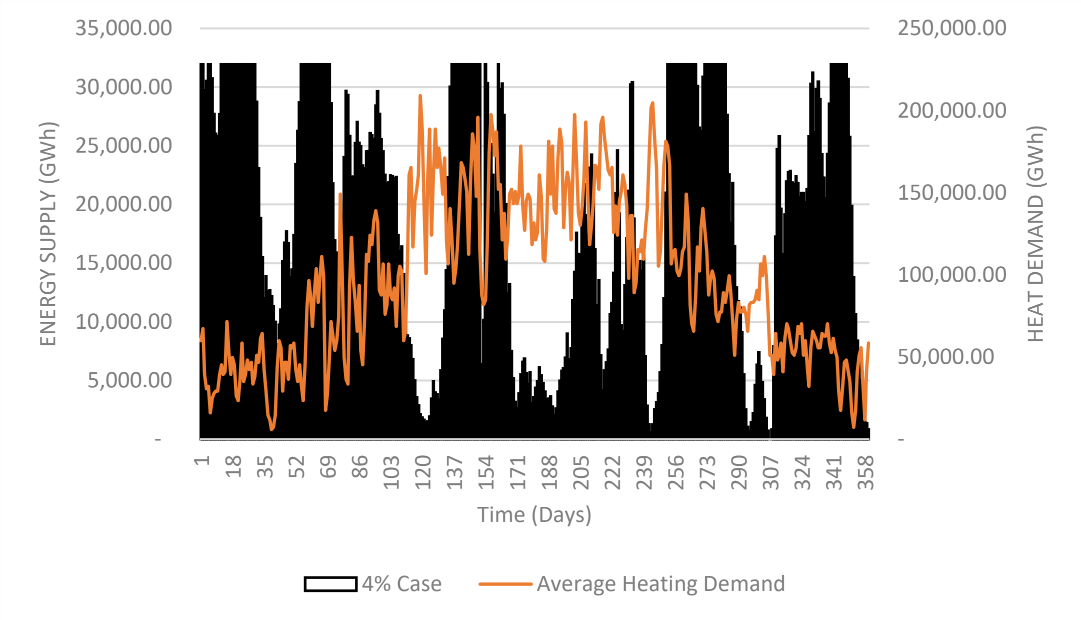


Figure 10: Supply & Demand of Current Building Designs

Annual Energy Demand= 65.72 GWh

Annual Energy Supply= 381.71 GWh

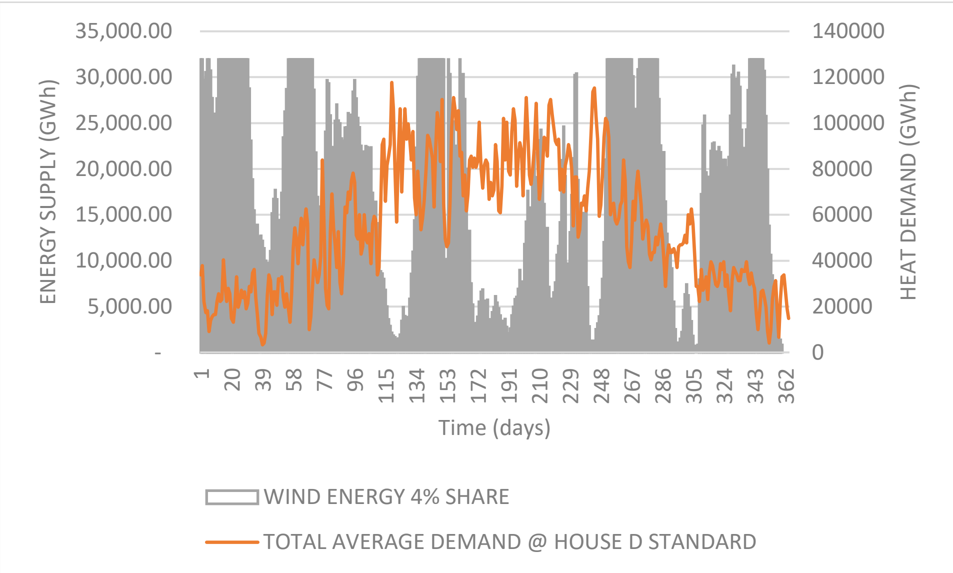


Figure 11: Upgraded Supply & Demand with House D as Island Build standard

Annual Energy Demand= 39.43 GWh

Annual Energy Supply= 381.71 GWh

The analysis shows us that in each case Islay would receive sufficient energy with a surplus to their current demand. With further turbine upgrades and increased sizing, there is potential for this to increase. Meeting demand on an annual basis seems simple enough, however, considering daily generations variability can impact the overall resource potential. Figures 9 & 10- show that wind produces significant amounts of energy however due to its intermittency it cannot be relied upon to meet demand requirements on all days.

Assuming all houses on Islay have been retrofitted and upgraded to the same building standards as House D, this would significantly reduce the overall energy demand. With this reduction energy from wind is still unable to match the heating demands of the Islands properties, as shown in Figure 10.

To address Intermittency a dispatchable energy storage system would be required, currently, there is a 6MW generator available however a greater storage capacity is required to supply heating demand during peak periods.   With total heating demand reaching up to 69,000kWh. A battery sized to match this demand is needed to support the grid.